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Partial Defect Verification of the Pressurized Water Reactor Spent Fuel Assemblies

Y. S. Ham, S. Sitaraman

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Young S. Ham and Shivakumar Sitaraman
Lawrence Livermore National Laboratory, Livermore, CA
E-mail address of main author: ham4@llnl.gov

INTRODUCTION

The International Atomic Energy Agency (IAEA) has the responsibility to carry out independent inspections of all nuclear material and facilities subject to safeguards agreements in order to verify compliance with non-proliferation commitments. New technologies have been continuously explored by the IAEA and Member States to improve the verification measures to account for declared inventory of nuclear material and detect clandestine diversion and production of nuclear materials. Even with these efforts, a technical safeguards challenge has remained for decades for the case of developing a method in identifying possible diversion of nuclear fuel pins from the Light Water Reactor (LWR) spent fuel assemblies.

We had embarked on this challenging task and successfully developed a novel methodology in detecting partial removal of fuel from pressurized water reactor spent fuel assemblies [1-5]. The methodology uses multiple tiny neutron and gamma detectors in the form of a cluster and a high precision driving system to obtain underwater radiation measurements inside a Pressurized Water Reactor (PWR) spent fuel assembly without any movement of the fuel. The data obtained in such a manner can provide spatial distribution of neutron and gamma flux within a spent fuel assembly. The combined information of gamma and neutron signature is used to produce base signatures and they are principally dependent on the geometry of the detector locations, and exhibit little sensitivity to initial enrichment , burn-up or cooling time. A small variation in the fuel bundle such as a few missing pins changes the shape of the signature to enable detection. This resulted in a breakthrough method which can be used to detect pin diversion without relying on the nuclear power plant operator's declared operation data. Presented are the results of various Monte Carlo simulation studies and experiments from actual commercial PWR spent fuel assemblies.

EXPERIMENTS

In order to validate the concept of the pin diversion methodology, experiments were conducted to measure neutron and gamma signals inside guide tubes of PWR spent fuel assemblies. Table 1 shows the fuel information of the three Westinghouse PWR fuel assemblies used for measurements whereas Figure 2 shows the location of fuel rod, control rod guide tube and instrumentation tube for the assemblies. Red color in Figure 2 represents positions where pins are removed.

Table 1: Description of the three PWR spent fuel assemblies used for experiments.

Fuel ID	Fuel Type	Burnup (GWd/tU)	Discharge Date	Initial Enrichment (%)	Number of missing rods
C15	WH 14x14	32.0	4/17/82	3.2	22 (12%)
G23	WH 14x14	35.5	10/24/86	3.2	25 (14%)
J14	WH 14x14	37.5	1/20/89	3.2	1 (0.6 %)

In-house developed underwater neutron measurement system was used to measure neutron signals inside guide tube holes in PWR spent fuel assemblies. A Centronic fission chamber was used for thermal neutron measurements in a waterproof housing, and IAEA standard electronics and software, i.e., Mini Multi-Channel Analyzer and WinMCS software, for data acquisition. For gamma measurements, a special type of ion chamber was fabricated by Technical Associates. The ion chamber was waterproof and could be directly inserted into guide tubes. Whereas a computer and data acquisition software were needed for thermal neutron measurements, the gamma radiation dose could be directly read from a dose reader in a digital format. Typically it took less than a few minutes for insertion of neutron detector, and additional 150 seconds for a single position measurement in MCS mode with channel time of 30 seconds.

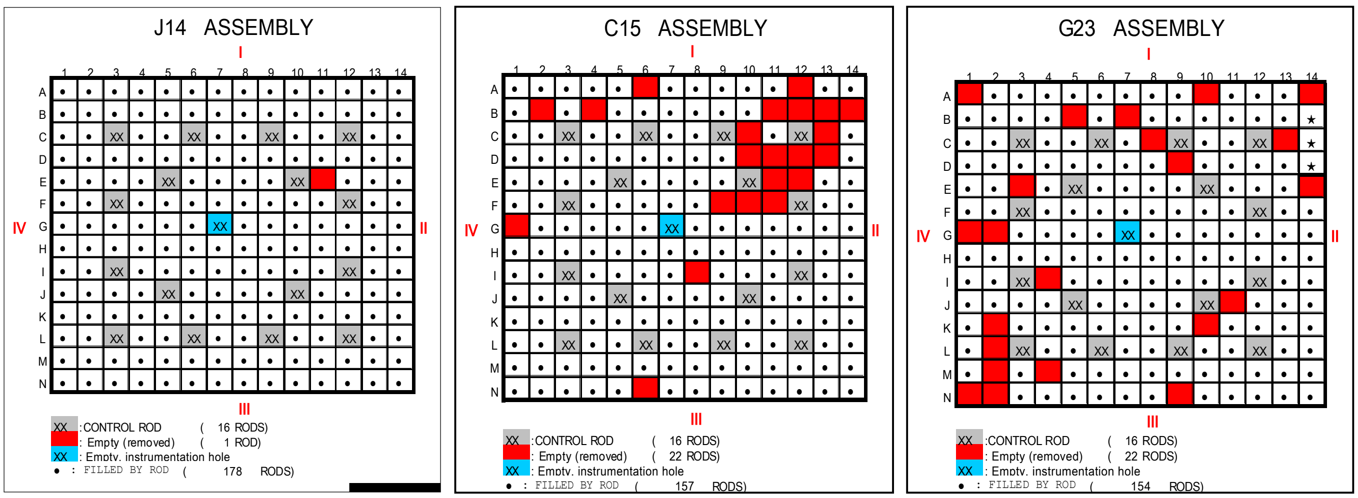

Figure 1: The diagram of fuel rod arrangement of three 14x14 PWR spent fuel assemblies (J14, C15 and G23) on which measurements were performed. Red color indicates positions where rods were removed and filled with water.

RESULT AND DISCUSSION

Figure 2 shows the neutron and gamma measurement results along with Monte Carlo simulated data. Both neutron and gamma agreed quite well with the simulated data. Note that the gamma flux is tallied at all energies inside the ion chamber without detailed tracking inside the chamber in the simulation whereas the experimental data indicate gamma dose.

Safeguards inspectors can use ratio profiles for PWR assembly verification, and gamma and neutron profile for confirmatory verification. If the ratio profile shows no deviation from the expected profile which should be symmetric and cyclic, no diversion can be assumed, for example J14. However, if the profile shows deviation from the expected profile such as the ratio profile for C15, the inspector can easily conclude that C15 is disturbed without even having the detailed knowledge of the C15 assembly. Note that the amount of diversion in this case was 12% whereas the current IAEA criterion for partial defect testing is 50%. For verification of G23, the neutron profile also deviated from the neutron base profile and it lacked the smooth symmetric pattern, an indication of disruption of the fuel integrity.

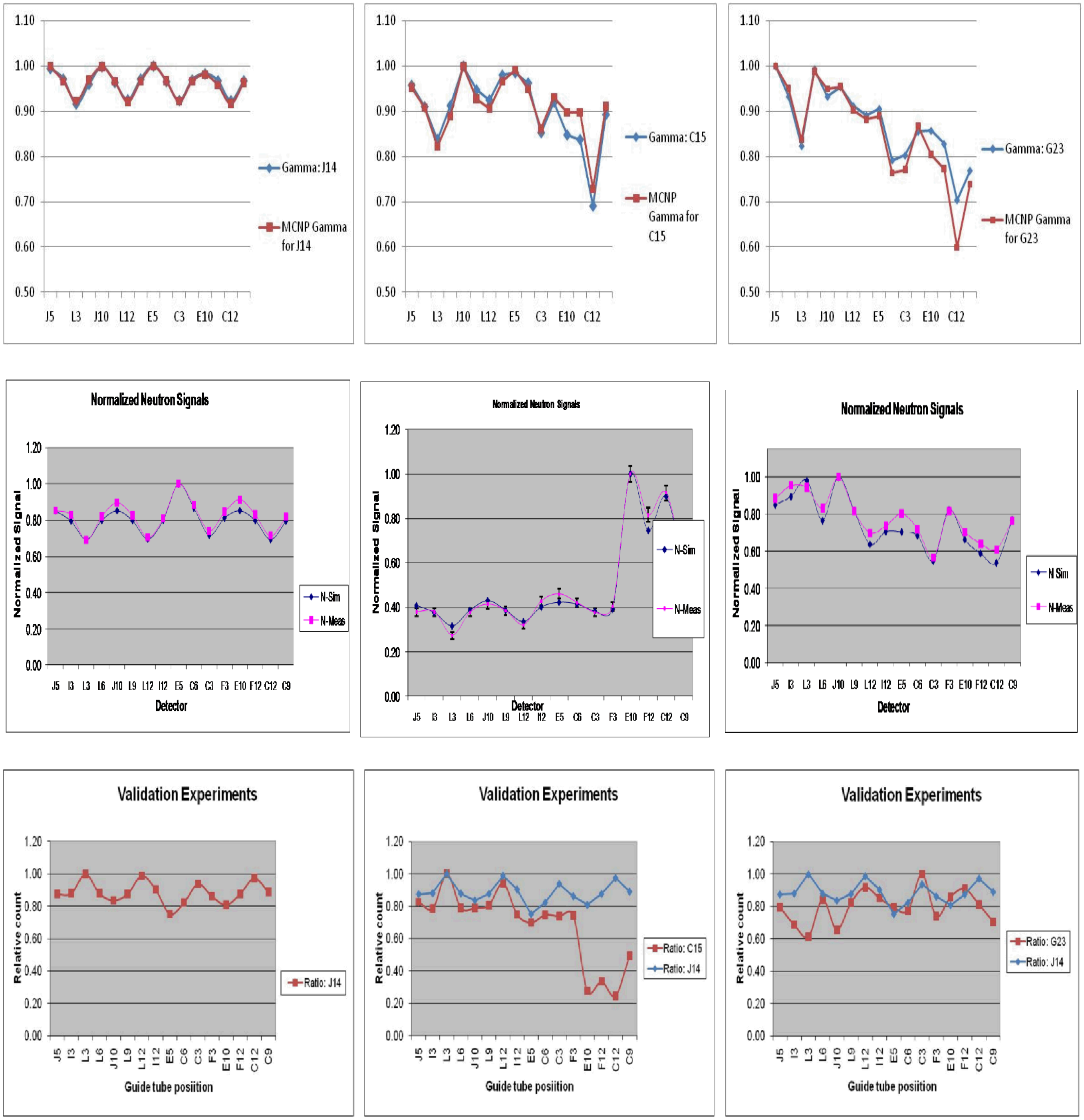

Figure 2: Comparison plots of experimental data with Monte Carlo simulated data for three 14x14 PWR spent fuel assemblies (J14, C15 and G23). They agreed well. The top row shows profile for gamma, the next row neutron and the bottom row the ratio of gamma to neutron.

CONCLUSION

The experiments demonstrated the validity of the verification methodology. The results from the experiments were compared with the simulations and the agreement between the two was well within ten percent. It demonstrated that the envisaged PDET system would be a new powerful safeguards tool for partial defect verification, which does not require movement of a spent fuel assembly from its stored location in the spent fuel rack or any operator provided data such as burnup or cooling time.

ACKNOWLEDGEMENT

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